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THE EVALUATION OF EXPERIMENTAL FABRICS AS ALTERNATIVES FOR STANDARD WOOL FABRICS

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THE EVALUATION OF EXPERIMENTAL FABRICS AS
ALTERNATES FOR STANDARD WOOL FABRICS

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SUMMARY

1) Since alteration in the wicking behavior is one of the obvious results of blending of synthetics with wool, some question has been raised as to the consequences of this phenomenon in warmth and comfort of clothing. Experiments have been conducted analagous to two differing types of use situations: 1) that corresponding to moist-warm conditions in which a single layer of cloth is in contact with a moist skin and one face freely exposed to the wind, and 2) that corresponding to cold weather conditions in which multilayers of fabrics are used and free exposure of some of the component layers is absent. Under the first test condition, the results show that more heat and moisture are transferred through a single layer of a wicking Orlon serge than through a slow wicking wool serge.

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The differences in behavior are explained by the relative quantities of liquid water present on the face of the fabrics in each case. Since some of the energy for evaporation is supplied from the wind stream rather than drawn entirely from the body, it cannot be certain, as yet, that more effective cooling <u>at the body surface</u> results from the use of wicking clothing under the experimental warm conditions.

2) Under conditions in which free exposure of the moist fabric to air is prevented, as in the interior layers of arctic assemblies the wet thermal resistance is not related to the wicking character of the fabric. This is demonstrated by the similar wet thermal resistance (with the two plate Cenco Fitch apparatus) of underwear made of wool and shrink-resistant wool, and of nylon and water repellent nylon. Similarly, chlorination treatment of two types of shirting is shown to be without effect on the wet thermal resistance.

With assemblies of initially dry serges over moist underwear, differences in thermal transfer at low pressures using either Orlon or wool serge are explained entirely by thickness differences of the assemblies. Drastic alteration of the wicking behavior of the wool serge in such an assembly by treatment with a rewetting agent produces no change in thermal resistance of the assembly. Assemblies of wicking and non-wicking serges exhibit similar losses of heat and moisture even when one face is exposed to the wind; thus the behavior of a double layer of Orlon approaches that of a single layer of wool serge of equivalent thickness. The resistance to transfer of water from fabric to fabric limits the wetting of the exposed outer layer and thus decreases evaporation and heat loss.

3) At the suggestion of the Philadelphia QM laboratory, a comparison of methods now used for measuring wicking was made in order to determine whether any

[redacted]

one of the methods was potentially suitable for specification purposes. With a group of fabrics differing widely in this property, very good agreement was found with the vertical strip method, a horizontal strip method and the drop absorption technique. The last of these, by virtue of its simplicity, appears to be most suitable for the fabrics studied.

4) British textile workers have recently rediscussed the potential benefits from the use of high regain fibers in clothing in preventing chilling. The thermostatic effect arises from the heat liberated during sorption of water vapor by the fiber. Using the best available data from the literature, it is shown that a substantial fraction of the metabolic heat may be realized during transfer of fibers from low to high relative humidity conditions (i.e. indoors to outdoors), the amount being proportional to the net regain change. Whether this heat is available under practical clothing conditions has not yet been demonstrated experimentally. Factors tending to decrease the amount of heat realized in practice are: 1) the slowness of diffusion of water vapor in air layers between fabrics, 2) the influence of body perspiration in minimizing regain changes in clothing fabrics.

DETAILS

I. Wet Thermal Measurements of Fabrics and Assemblies

A. Introduction

Since one of the obvious effects of synthetic fibers in blends with wool is to increase the wicking rate, some study has been given to the consequences of this effect on the thermal resistance of fabrics. Measurements were made using various underwear fabrics which have been well characterized in respect to their wetting and wicking behavior. In addition, preliminary measurements using assemblies of fabrics are reported which, while more complex physically, correspond more realistically to the use condition.

B. Underwear Fabrics

Thermal resistance was determined as previously described with the Cenco-Fitch apparatus. The details of the fabric properties have been given in Report 6. Wicking characteristics of the underwear fabrics measured at that time were shown to be: Very rapid -- Cotton (RD 68); Moderate -- Nylon (RD 62) and Shrink-resistant Wool (RD 70); Very slow -- Wool (RD 86) and Water-repellent Nylon (RD 65).

The intrinsic thermal resistances (C° sec m^2/cal) of the five underwear fabrics are summarized in Figure 1, being plotted as a function of moisture content. Specific thermal resistances (intrinsic thermal resistance divided by thickness) in units of C° sec m^2/cal in. are given adjacent to the points of Figure 1. The data for all of the underwear fabrics illustrate the decrease in insulation with added moisture. The wool fabrics exhibit higher intrinsic thermal resistances at all moisture contents than the other fabrics tested. This is only partly due to the greater thickness; when corrected to unit thickness the wool

underwear at these test conditions is still greater by 20-50% in specific resistance than the nylon underwear.

It is important to note that this effect is not a consequence of the wicking behavior as measured by transport rates or by drop absorption. This is demonstrated by the similar wet thermal behavior of the pair of wool underwear fabrics, one relatively rapid in wicking and one quite slow, and by the pair of nylon fabrics which are also identical in thermal behavior and yet have quite different wicking rates. Of interest also, is the fact that the specific thermal resistances of the shrink-resistant wool and of the nylon underwear are not the same despite the similarity in wicking behavior. Thus, contrary to the indications from an earlier trial with serges (Report 8), it is concluded that a relationship between wet thermal properties and wicking is not a general one. In the present case, the lower specific resistances of cotton compared with nylon and wool or of nylon compared with wool must arise from other sources:

1) The arrangement of the fibers at the fabric surfaces would be different with the several fiber types and this could lead to differences in the efficiency of thermal transfer from the fabric to the heat source and receiver of the apparatus; indeed, the "hot penny" data given previously (Report 6) show the cotton fabric to be least hairy, the wool samples most hairy and the nylon fabrics intermediate.

2) The conductance of the fiber substance and/or the arrangement of the fibers (and hence of the water) in the yarn and fabric might well be expected to differ. This possibility has been discussed in Report 6 in respect to the thermal resistance of dry fabrics and seems applicable to the wet case,

C. Shirting Fabrics: Effect of Chlorination

A question related to the comfort behavior and wicking is the effect on thermal properties of shrink-resistance treatment, these being known to alter the wetting behavior of fabrics in some cases. While the results in the previous section indicated that the wet thermal properties of untreated and shrink-resistant underwear were virtually identical it was considered desirable to verify this with another fabric type. Two jack-shirting types of cloth were available which had been mill treated by a chlorination process, samples being taken before and after treatment. Thermal measurements were made as before but at thicknesses corresponding to pressures of 1.0 lb/in^2. Typical results are given in Table 1. The treatment for shrink-resistance is seen to produce no alternation in the thermal resistance of the shirtings either in the air dry state or with additional moisture. It is interesting to note however that the blend exhibits lower thermal resistance than the comparable all wool fabric again illustrating the specific effect of fiber type and arrangement.

D. Assemblies: Serge over Underwear

Experiments were performed on assemblies consisting of a single layer of serge over a single layer of underwear, the latter containing varying amounts of moisture. This experimental condition may be thought of as analagous to the use condition in which active sweating occurs. Tests were made with an initial temperature differential of 23 to -10°C, such that frosting occurred on the cold (serge) face, and at thicknesses corresponding to 0.01 and 0.1 lb/in^2. The results at 0.01 lb/in^2 are summarized in Figure 2.

The curves show the similarity in behavior of the assemblies irrespective of the type of serge used. The greater thermal resistance of

the wool serge-underwear assembly may be attributed to the greater thickness, since, when corrected to unit thickness, the specific resistances (figures adjacent to curves) are identical within experimental error. This is confirmed by the fact that shearing of the wool serge to a thickness equal to that of the Orlon serge, results in an observed thermal resistance equal to that of the Orlon serge in an assembly. Thus under these conditions, the wet thermal results are explainable simply in terms of the thickness of the assembly and the degree of wetness of the underlayer rather than to any effects due to wicking of the upper serge layer.

Somewhat different results were obtained in a more limited series of trials measured at a higher pressure - 0.1 lb/in^2. The initial temperature gradient was 23 to -10°C as before but nylon underwear was employed for the under-layer. This change was made to avoid curling and related manipulative difficulties encountered with the wool underwear after it had been shown that this substitution was without effect on the thermal results. Results obtained with the nylon underwear containing initially about 25% moisture are given in Table 2.

Comparison of the data in which wool or Orlon serge was used in the upper layers shows the greater intrinsic resistance of the assembly containing wool. This result is only partially explained by the difference in thickness since the calculated specific resistances are still dissimilar outside experimental variability. That an inherent difference besides thickness exists, between the Orlon and the wool assemblies, in this group of experiments is also shown by the results obtained with the sheared wool and with the napped Orlon serge. Despite the equivalence in thickness (comparing the napped Orlon with the wool and the sheared wool with the Orlon assembly), the assembly

containing the wool serge always exhibits greater thermal resistance than the corresponding Orlon member of the pair.

It was thought possible that in this instance the differences in wicking behavior might account for the thermal properties observed. To test this possibility, the wool serge in its original state and after shearing was treated by immersion in a dilute solution of an anionic wetting agent and dried; it was observed that the treated cloth exhibited instantaneous wetting. As shown in Table 2 the thermal resistances of the treated fabrics in contact with a moist underwear layer are virtually unaltered in comparison with the untreated materials. This finding indicates that wicking per se is again unimportant in respect to thermal behavior under the test conditions employed.

Experimental work is now going forward to determine assembly behavior under other conditions of temperature and plate separation.

It seems possible from examination of the current results that the type of fabric to fabric contact in an assembly may be of some importance in the overall behavior. The kind of "wicking" in which water is transferred from a moist to a dry fabric appears to be involved in the process studied and this area will be investigated further.

E. "Sweating Arm" Experiments

The results just described were designed to evaluate the thermal behavior of a single layer or layers in the interior of a thick garment assembly, e.g. an arctic assembly. Since the warm-moist situation, in which a sweating "skin" is covered by a thin layer of fabric exposed to moving air, is also of interest, studies with the "sweating arm" apparatus have been continued. The

effects of fabric wicking under conditions of free exposure to the wind were expected to be of concern in warm weather clothing or in cold weather assemblies under high levels of body activity. The results for moisture and heat losses in the following sections are given in terms of grams of water lost per hour per cm of water vapor pressure difference between skin and ambient and in terms of the electrical energy required to maintain the skin at constant temperature in units of watts per cm of water vapor pressure difference.

1) The Effect of Fabric Wetness

The results of wind tunnel measurements on an Orlon serge (20) and a wool serge (17) at various stages of wetness are given in Table 3. With initially dry samples, water rapidly penetrates to the top surface of the Orlon fabric which becomes visibly wet. This type of surface wetness is not present in measurements with the wool fabric. The Orlon serge gives rise to correspondingly greater heat and moisture losses than does the wool serge. These observations suggest that water evaporation from the Orlon fabric can occur at the top (windstream) surface while that from the wool fabric occurs at the bottom (skin) surface of each fabric. A means of verifying this hypothesis is to make the wool and Orlon fabrics more similar in respect to surface wetness by wetting them out before wind tunnel experiments. Results on initially wet fabrics are also given in Table 3. Both wool and Orlon pre-wet samples exhibit an increase in moisture loss over that of the dry samples and indeed become experimentally indistinguishable from one another when starting from the wet state. These results indicate that given a sufficient supply of moisture at the fabric surface, the wind stream is capable of evaporating substantial amounts

of water from it irrespective of the nature of the fiber. The Orlon serge starting from the air dry condition, approaches this wet state rather quickly as a consequence of its rapid wicking ability and hence is normally similar to the pre-wet state. In the case of the wool fabric, a wet state is not normally reached in the course of a wind tunnel run. Thus, the site of evaporation is usually near the "skin" side of the fabric and evaporation shifts to the wind-stream face only if the fabric is pre-wet.

It is important to note, however, that the greater losses with materials that exhibit high surface wetness do not necessarily imply greater cooling effect at the body surface since part of the energy for evaporative cooling comes from the wind stream. This is shown by the decrease in the evaporative cooling ratio for both pre-wet fabrics to a low value of 0.6 to 0.7. Measurements are now in progress to see if the temperatures of the under and outer fabric surfaces reflect this change in location of the evaporation region and this work should permit better assessment of the role of wicking on comfort under warm conditions.

2) The Effects of Shearing, Napping, and Fabric Layers

Test serge fabrics 17 (wool) and 20 (Orlon) were napped and sheared for studies of the influence of surface properties of the fabric on heat and moisture transfer. The results on these fabrics examined in wind tunnel experiments are given in Table 4. The results with the wool serge at 4.7 mph. indicate the existance of an effective barrier to the transport of water, perhaps a still air diffusion layer on the skin side of the fuzzy fabric surface. This

is suggested by the lack of change in water and power losses upon napping as well as in experiments with a double layer of the wool serge. Shearing appears to decrease the thickness of the barrier which would be stabilized by the surface fibers and penetration by the wind on the exposed face of the fabric is facilitated. This effect is seen in the small but significant increase in water loss and the corresponding increase in power loss obtained by shearing the wool fabric. The single and double layers of wool serge exhibit appreciably higher moisture transfer in a wind stream of 15.2 mph. than at 4.7 mph. The increases in power losses are proportionally smaller because a greater fraction of the energy for evaporation is supplied by the windstream at the higher wind velocity.

In the case of the Orlon serge, the air stream face of the test specimen becomes wet quickly in a wind tunnel experiment as noted previously. Thus, at the end of a two hour run, the specimen may contain as much as 65 per cent of its air dry weight as moisture (see Table 3). The water losses (and the corresponding power losses) are relatively large due to the free water available to the wind stream at both 4.7 and 15 mph. Napping is effective in interposing a barrier to the transfer of water as shown by the decreased losses with a napped Orlon fabric. This resistance to transfer by the napped cloth may conceivably be due to two causes: (1) The establishment of diffusion barriers of still air type at the skin and at the air stream faces, and (2) A decrease in the initial rate of liquid water transfer from the wet "skin" because of the enhanced a hairiness.

It is interesting to note that the water and power losses with the Orlon serge are lowered even further in the double layer experiments.

This result is clearly in response to a decrease in overall wicking by the assembly, and hence to a decrease in availability of liquid water to the moving air stream. Thus, while the skin-side layer of serge contains about 60 per cent moisture, the air-stream side is virtually air-dry. The skinward shift in the site of evaporation is also reflected in the increase in evaporative cooling ratio at 4.7 mph. from 0.85 for the single layer to 1.01 for the double layer. Indeed, the behavior of the double layer of Orlon serge in respect to water and power losses from the "sweating arm" approaches that of the single wool layer of equivalent thickness. With the wicking fabric studied, the use of double layers interposes an additional barrier to moisture transfer--that between fabric to fabric. Thus, in these experiments, in which one fabric face of an assembly is exposed to air, wicking appears to have little influence on the wet thermal losses and this is in agreement with the Cenco-Fitch studies previously described. The fact that this behavior is in contrast with the single layer studies suggests that in addition to wicking customarily measured, the extent of water transfer from a moist to a dry fabric may be of importance in the study of assemblies.

F. The Effects of Gaps and Holes in Clothing

The use of short sleeves and open collars as aids to cooling for clothed humans under warm-wet stress conditions is well recognized. Wind tunnel experiments on a fabric having varying numbers of holes were carried out at two wind speeds to examine this effect in a more quantitative way than previously reported. The results for tests on the wool serge fabric (17) are summarized in Table 5.

At the slow windspeed (4.7 mph.) two 1/2" diameter holes in the 11.5" x 3.7" samples increased water losses appreciably over the control; however, water losses with 6 additional holes are about the same as with 2 holes. At a wind velocity of 15.2 mph. the influence of an increase in number of holes in the fabric extends at least to 8 holes. Thus it can be seen that the existence of gaps and exposed areas of the skin can be of great utility in influencing increased moisture losses under warm stress conditions and this is in conformance with practical experience. The results further illustrate that while the cooling experienced because of the skin exposure is noticeable at low wind speeds, the amount really becomes of consequence as the wind velocity is increased.

In these experiments the power losses were altered only slightly by the exposure of skin surface. This is probably a reflection of a partial change in location of the site of evaporation from the skin surface under the fabric to the free sweating surface at the holes. Heat for evaporation from the free sweating surface comes mainly from the windstream with only a moderate contribution from the sweating surface, and so the power losses from the cell show only moderate changes as the number of surface holes is increased.

II. Interlaboratory Comparison of Wicking Tests

A. Introduction

A property in which fabric blends exhibit sizeable differences and which has received considerable attention both at the Textile Materials Engineering Laboratory and in these laboratories is that of wicking. The methods used to study relative wicking rates of fabrics in the two laboratories differ somewhat

in form and principle. At the request of the Philadelphia Laboratory, comparisons among these methods were made as a step towards setting up a more uniform approach for evaluating this property for potential use in specifications. Accordingly, fabric samples of contrasting construction and material were selected by the Philadelphia laboratory. These were laundered, cut into 1" strips, and each strip cut in two (lengthwise) so that one half would be available for testing in each laboratory.

B. Experimental Methods

The wicking test in current use for evaluating the water transport properties of fabrics at the Textile Materials Engineering Laboratory involves measurement of the time required for water to travel known distances in a strip of fabric suspended vertically with one end in a reservoir of water.

The Harris Research Laboratory method for examining water transport along a fabric is also carried out on strips, one end of which is dipped in a reservoir of water. However in this test the strips are supported horizontally on a series of pairs of contact pins spaced at intervals from the reservoir. The square of the distance of water travel is plotted against the time and the slope of this curve in units of cm^2/sec is the horizontal wicking rate.

A second test related to wicking is used in the Harris laboratories. The time taken for 0.2 ml of water, placed on the surface of a fabric, to penetrate the fabric is called the drop absorption time and is used as a measure of the surface wetting property of a fabric.

C. Wicking Results

The results of wicking tests carried out by the two laboratories on ten fabrics of contrasting construction and fiber material are summarized in Table 6. In this table the fabrics have been arranged in decreasing order of wicking rate or increasing order of wicking time. Agreement between the methods on a relative and on an absolute basis is excellent. Fabric 10, a treated acetate taffeta, exhibited a wide spread in wicking times from sample to sample indicative of uneven treatment, but the figures for this fabric are within experimental error of the "slow" wicking class.

D. Discussion

The results of Table 3 suggest that any one of the wicking methods would be successful in classifying the wicking behavior of these fabrics. That the drop absorption times rate the fabrics in a similar manner to the other wicking tests is probably a reflection of the fact that fast wicking fabrics generally have a smooth surface and slow wicking fabrics generally have a fuzzy surface. The result for fabric 10 is again somewhat anomolous but this is directly traceable to the fact that the drop absorption time is lowered by wicking along the bench under the fabric. A modified drop absorption test with the fabric suspended horizontally out of contact with another surface is suggested by this observation.

The agreement between the two methods for measuring wicking behavior "along" a fabric is to be expected. In both tests the driving force for wicking is capillary action between the fibers of the yarns. The classical laws of capillary penetration predict a linear relation between the square of the wicking

distance and time in horizontal penetration (HRL method) and a similar relation somewhat modified by gravitational forces for vertical penetration (TMEL method). The deviation from linearity becomes more marked with fabrics of lower wicking rates. For this reason, it would be theoretically incorrect to calculate a single wicking rate from data obtained from the vertical wicking test as has been suggested from time to time. On the other hand use of several wicking times as being representative of general wicking behavior is certainly adequate and gives, as shown by this interlaboratory comparison, good agreement with data on horizontal penetration. Indeed, except for special fabrics of unusual surface character, the drop absorption test is probably quite adequate for classifying fabrics according to their relative wicking ability and in view of its simplicity could be recommended for most specification purposes.

III. Relation of the Water Sorptive Ability of Fibers to Comfort in Clothing

A. Introduction

Textile fibers derived from cellulose products (cotton, viscose, acetate, etc.) and from protein materials (wool, silk, Vicara) differ from the organic synthetic fibers (nylon, the acrylics, Dacron) in one major physico-chemical aspect which may give rise to differences in their behavior in textile assemblies. The first class sorb water in appreciable amounts from a moist atmosphere and indeed the amount sorbed or the "regain" of the material constitutes an appreciable portion of the weight of fabrics made from these materials. In contrast, fibers made from materials of the second class, exhibit very small moisture regain values.

The sorption of moisture by all materials is accompanied by the evolution of heat. The amount of heat evolved is proportional to the amount of water taken up and to the "tightness" of the binding of the water on the solid material. This "tightness" of the binding of water is reflected in the magnitude of the heat of sorption of the process.

Cassie and co-workers were among the first to discuss the magnitude of the heating produced by wool fabrics exposed consecutively to dry (indoor) and moist (outdoor) atmospheric conditions. Their experiments revealed that the amount of heat produced by the moisture sorbed was of the same order of magnitude as the metabolic heat produced by the body, and they suggested that much of the comfort imparted by wool fabrics under such conditions was due to this "heat of sorption" effect. In a recent talk before the British Association, Cassie has again emphasized the importance of this behavior of fibrous materials and has given calculations to show that temperature differentials in the fabrics due to moisture sorption tend to slow cooling by thermal transmission through the fabric as well as to reduce the total temperature drop attained by such a fabric under cold-moist conditions. In other words, textile materials, by virtue of their ability to absorb moisture, can potentially afford the body protection against sudden temperature changes at the outer layer of clothing and hence at the skin. This thermostatic action of clothing fibers has a bearing, therefore, on the comfort aspects of fabrics and blends for cold weather use. In view of the interest aroused by Cassie's recent discussion of this subject, the principles involved in evaluation of the heat of sorption effect are reviewed below and these are considered in connection with their application to several fiber types under

practical environmental conditions.

B. Heats of Sorption

The process of sorption of water vapor by textile fibers is accompanied by the evolution of heat and the heat evolved arises both from the condensation of water on the sorption surface (L) and from the energy of binding of the liquid to the solid surface (Q). Hence, the heat of sorption may for purposes of measurement and calculation be considered as related to the sum of the two terms, L + Q. The contribution of the first term, L, to the heat of sorption depends only on the amount of water involved. The magnitude of the second term, Q, depends on; a) the nature of the absorbing substance, b) the amount of moisture absorbed, and c) the initial state of regain of the fiber, The regain of the fiber prior to the action of water sorption is important because the heat of wetting is highest at very low moisture contents and hence, under the usual circumstances of textile exposure, the maximum amount of heat from this source is not realized.

Data have been assembled (Table 7) to illustrate the heat of sorption effect in a typical case involving transfer of several textile materials from a warm-dry (indoors) condition at 30°C and 33.5% relative humidity to a cool-moist (outdoors) condition at 15°C and 90% relative humidity. These conditions are reasonably realistic and data are available from sorption measurements in this range.

Since the heat of sorption depends on the amount of water sorbed, reported investigations on the sorption of water by fibers were extensively reviewed and the best data for wool, viscose, cotton, and nylon were used to

calculate the regain figures of Table 7. The values for the "indoor" condition of this table are desorption regain figures and the values for the "outdoor" condition are sorption figures. The difference between these values, then, represents the net gain in water in a kilogram of fiber on being transferred from the warm-dry to the cool-moist state in the example chosen.

Experimentally, the heat of wetting, Q, can be determined calorimetrically by measurement of the amount of heat liberated by the successive additions of small amounts of water to a known mass of fiber. Such measurements on a variety of fiber types have been conducted very recently by the Bureau of Standards and the results made available to us through the kindness of Dr. J. R. Kanagy. This work agrees well with previously published data and was used to compute heat of wetting values, Q, for the moisture conditions of the example. The heat of condensation, L, from the International Steam Tables, is 584 cal/gm at 22.5°C and the "unit" heat of sorption per gram of water, L + Q, is given in Table 7. It is clear that the heat of condensation, L, is of much greater consequence than the heat of wetting, the former being two orders of magnitude larger. Hence the total heat of sorption, obtained from the product of the unit heat of sorption and the net water gain, is mainly influenced by the amount of water sorbed by the fiber in any given case. For the example conditions in Table 7, the total amount of heat ideally achievable is high for the high-regain fibers, viscose and wool, and is low for the lower regain fibers, cotton and nylon.

C. Discussion

It is to be emphasized that the heat of sorption values calculated in

Table 7 represent the maxima obtainable under the example conditions chosen. Under other conditions, however, it is clear from the principle which has been established that the extent of sorptive heating could be predicted from the net changes in moisture content. Thus fibers may be grouped with respect to their capacity to exhibit a heat of sorption effect based strictly on their relative regains.

It has been stressed by Rees and by Cassie that the amount of heat available from fabrics in transferring them from a dry to a moist atmosphere is at least a substantial fraction of the metabolic heat. For a moderate level of activity, the metabolic heat production may be on the order of 200 kilocalories/hour and hence in the example cited the heat available from sorption could amount to 15 to 50 percent of the metabolic rate depending on the fiber type.

An important aspect of this problem for which there is as yet no unequivocal answer is with respect to how much of the total heat of sorption is made available in practice. Cassie has developed a theory of heat propagation which accounts for the slow rate of conditioning in terms of the heat of sorption. His experimental work involved the measurement of the temperature change of a plug of fibers when air flowing through it was suddenly changed in temperature and relative humidity. Consistent with his theory, his results clearly demonstrated the thermostatic effect with various fibers, the resistance to changes in temperature being proportional to the slope of the regain-relative humidity curve. Under diffusion conditions, the observed rate of temperature change is substantially slowed so that even relatively low regain fibers,e.g. cotton

(the lowest regain fiber employed by Cassie), may take many hours to reach temperature equilibrium. In terms of the use condition, therefore, experimental evidence is still lacking as to the relative influence of the heat of sorption and of diffusion in offering significant protection against rapid change in temperature of a fabric. It seems reasonable to suggest that the practical case will most often be some place between the diffusion and the forced circulation conditions employed in Cassie's experiments. The approach to diffusion conditions in the still air layers at the surface and between fabric layers in cold weather assemblies could, however, tend to delay temperature propagation even with low regain materials. Confirmation of this may be found in the observation that similar times are generally required for moisture conditioning of textiles in constant humidity rooms irrespective of type of fiber present. This operation is related to temperature propagation in that Cassie has shown that the achievement of moisture equilibrium and temperature equilibrium are equivalent manifestations of the same phenomenon. Experimental studies on the rate of regain change are being made in order to obtain a more quantitative picture of this process. Indications of the importance of the still air layer and of diffusion effects have been indicated by preliminary results which reveal a slower rate of conditioning for fuzzy fabrics than for smooth fabrics.

There is a second effect which is operative in clothing worn on the body which also affects the heat realizable from the sorption of water. The body continually dissipates moisture, roughly 3600 gms. per hour for a man walking and under normal thermal load. The net result is to keep the body side of clothing fabrics at a somewhat higher relative humidity than ambient conditions

Ogden and Rees have shown that for ambient temperatures well below freezing the relative humidity in the area between skin and fabric probably never rises much above 50%. However for warmer temperatures and with the subject under working conditions the humidity in this region may approach saturation. Thus, only the very outer layers of a garmet may reach the regain of the ambient, and hence relative humidities used in calculating the regain figures of Table 7 would be much too low for clothes worn on the body. The resulting changes in regain, and hence heats of sorption, would then be appreciably less, perhaps by as much as 50%.

While much of the discussion of the advantages of high regain fibers has been with respect to resistance to chilling, it should be made clear that the same thermostatic phenomenon might well be disadvantageous in situations in which physical activity leads to appreciable sweating in either cold or warm exposures. In these instances, the sorption of moisture from the body by high regain fibers would, by liberation of the heat of sorption, tend to nullify any cooling achieved by evaporation from the skin.

LIMITED USE DOCUMENT

TABLE 1 REPORT 10

THERMAL RESISTANCE OF SHIRTING FABRICS,

TEMP. GRADIENT 23 to 50°C, PRESSURE 1.0 LB/IN.^{2}

Fiber Content	Moisture Content a) %	Specific Thermal Resistance Before Treatment b) C°m^2 sec/cal in x 10^3	After Treatment b) C°m^2 sec/cal in x 10^3
Wool	0	2.05	2.02
	14	1.46	1.45
	49	1.04	1.04
70/30 Wool-Viscose	0	1.92	1.87
	15	1.20	1.31
	51	0.90	0.92

a) Above standard conditioned weight.

b) For shrink-resistance using a commercial chlorination process.

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TABLE 2 REPORT 10

THERMAL RESISTANCE OF ASSEMBLIES (SERGE OVER MOIST UNDERWEAR), INIT. TEMP. GRADIENT 23 to -10°C, PRESSURE 0.1 LB/IN^2.

Upper Serge Fabric	Init. Moisture Content of Nylon Underwear %	Thickness of Assembly mils	Thermal Resistance Intrinsic C° sec m^2/cal	Specific C° sec m^2/cal in
Wool (17)	27	89	0.122	1.38 x 10^3
Orlon (20)	26	73	.091	1.25
Sheared Wool (17)	25	73	.102	1.40
Napped Orlon (20)	25	87	.112	1.29
Treated* Wool (17)	25	87	.124	1.42
Treated* Sheared Wool (17)	27	75	.104	1.39

* Treated with anionic wetting agent to produce rapid wicking

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TABLE 3 REPORT 10

HEAT AND MOISTURE TRANSFER THROUGH SERGE FABRICS AS A FUNCTION OF FABRIC WETNESS, TEMP. DIFF. 7C°, WIND VELOCITY 4.7 m.p.h.

Fabric	Moisture Content[a] %	Net Normalized[b] Water Loss gm/cm hr	Net Normalized[b] Power Loss watts/cm	Evaporative[c] Cooling Ratio
20 (Orlon)	0 (Initial) 65 (Final)	3.50	2.0	0.85
20 (Orlon)	76 (Mean)	4.16	2.0	0.72
"	71 (Mean	4.22	1.9	0.67
17 (Wool)	0 (Initial)	1.87	1.5	1.20
"	77 (Mean)	4.44	1.9	0.64
"	73 (Mean)	4.72	1.9	0.60

a) Above conditioned weight.

b) Corrected for edge and cell insulation losses.

c) Defined as the ratio of the sweating cell heat loss to the heat required to evaporate all the water lost.

~~LIMITED USE DOCUMENT~~

TABLE 4 REPORT 10

HEAT AND MOISTURE LOSS THROUGH SERGE FABRICS AS A FUNCTION OF THICKNESS AND SURFACE,

TEMP. DIFF. 7C°.

Fabric	Condition	Thickness at .01 lbs/in^2 mils	Wind Velocity 4.7 m.p.h		Wind Velocity 15.2 m.p.h.	
			Net Normalized Water Loss gm/cm hr	Net Normalized Power Loss Watts/cm	Net Normalized Water Loss gm/cm hr	Net Normalized Power Loss Watts/cm
17 (Wool)	single layer	69	2.02	1.5	3.3	1.7
	sheared	45	2.24	1.7	-	-
	napped	106	1.93	1.6	-	-
	double layer	118	2.03	1.6	3.5	1.8
20 (Orlon)	single layer	35	3.50	2.0	4.4	3.0
	napped	70	2.97	1.9	-	-
	double layer	71	2.50	1.7	3.5	1.8

LIMITED USE DOCUMENT

TABLE 5 REPORT 10

HEAT AND MOISTURE TRANSFER THROUGH WOOL SERGE FABRIC 17 CONTAINING GAPS AND HOLES, TEMP. DIFF. 7C°.

Number of 1/2" Diameter Holes	Wind Velocity 4.7 m.p.h. Net Normalized Water Loss gm/cm hr	Wind Velocity 4.7 m.p.h. Net Normalized Power Loss watts/cm	Wind Velocity 15.2 m.p.h. Net Normalized Water Loss gm/cm hr	Wind Velocity 15.2 m.p.h. Net Normalized Power Loss watts/cm
0	1.88	1.4	2.5	2.1
2	2.21	1.3	3.0	2.1
8	2.19	1.4	3.3	2.4

~~LIMITED USE DOCUMENT~~

TABLE 6 REPORT 10

A COMPARISON OF WICKING TESTS

Fabric No.	Fabric* Description	TMEL Vertical Test: Time to Wick 1" Minutes	TMEL Vertical Test: Time to Wick 1/4" Minutes	HRL Methods: Horizontal Wicking Rate $cm^2/sec \times 10^3$	HRL Methods: Drop Absorption Time Seconds	Wicking Class
9	100% Viscose, banner cloth	1/4	1/4	190	3	Very fast
1	100% Cotton, permeable cloth	1/4	1/4	200	1	Very fast
3	100% Orlon, serge	1/2	1/4	120	3	Very fast
6	30% Viscose, serge	3-3/4	1/2	27	170	Fast
5	30% Dynel, serge	6-1/2	2-1/2	29	460	Fast
7	100% Cotton, duck	18	6	14	910	Moderate
10	100% Acetate, treated taffeta	1440+	1440+	3.9	690	Slow
2	50% Cotton, (Chlorinated Wool) underwear	1440+	1440+	0.2	29000+	Very slow
4	100% Wool, tropical worsted	1440+	1440+	0.2	29000+	Very slow
8	100% Chlorinated wool blanket	960+	1440+	0.2	29000+	Very slow

*Blend percentages not given are for wool.

TABLE 7 REPORT 10

WATER SORBED AND TOTAL HEAT AVAILABLE FROM TRANSFER OF FIBERS FROM LOW TO HIGH HUMIDITY

	Viscose	Wool	Cotton	Nylon
Sorption Regain (90% RH, 15°C), $\frac{g.H_2O}{kg.fiber}$	275	237	130	69
Desorption Regain (33.5% RH, 30°C), $\frac{g.H_2O}{kg.fiber}$	98	105	69	20
Net Water Gain $\binom{33.5\%\ RH,\ 30°C)}{(to\ 90\%\ RH,\ 15°C}$, $\frac{g.H_2O}{kg.fiber}$	177	132	61	49
Heat of Wetting, Q $\left(\begin{matrix}33.5\ to\ 90\%\ RH,\\ 25°C\end{matrix}\right)$, cal/g. H_2O	8.0	7.3	3.5	1.8
Heat of Condensation, L (22.5°C), cal/g.H_2O	584	584	584	584
Unit Heat of Sorption (L + Q), cal/g. H_2O	592	591	588	586
Total Heat of Sorption $\left(\begin{matrix}33.5\%\ RH,\ 30°C\ to\\ 90\%\ RH,\ 15°C\end{matrix}\right)$ $\frac{kilocal}{kg.fiber}$	105	78	36	29

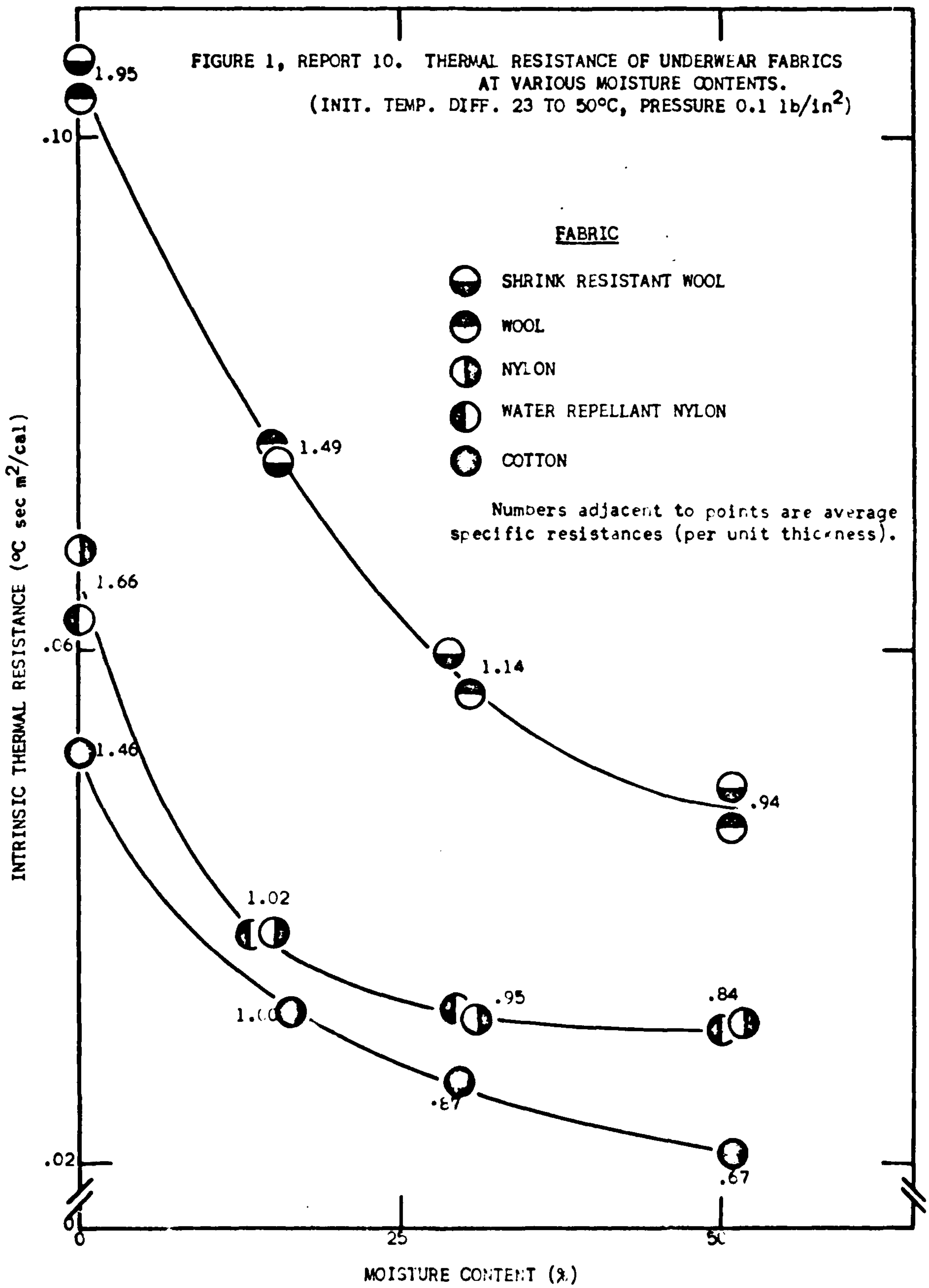
FIGURE 1, REPORT 10. THERMAL RESISTANCE OF UNDERWEAR FABRICS AT VARIOUS MOISTURE CONTENTS. (INIT. TEMP. DIFF. 23 TO 50°C, PRESSURE 0.1 lb/in²)

FIGURE 2, REPORT 10. THERMAL MEASUREMENTS OF WOOL OR ORLON SERGES OVER MOIST WOOL UNDERWEAR (INIT. TEMP. DIFF. 23 TO -10°C, PRESSURE 0.1 lb/in^2)